A Process for Robust Design of a Vehicle Front Structure Using Statistical Approach

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Abstract

In recent years, it has become more and more important to take scatter into account in automotive industry. Liability and performance has been guaranteed by adding safety margin to its target in the past. However, needs in cost reduction and trade-off of conflicting requirements do not allow manufacturers enough amount of safety margin any longer[1].

One way to reduce scatter in product performance is to control production quality. However, too much control increases managing cost, and scatter cannot be reduced more than tolerance specified by standards. There are some studies showing major scatters in response are sensitive to boundary conditions such as dummy position and offset or angle of crash barriers[1,2]. However, these are set up by third parties in hardware tests so that the parameters are beyond control[3].

For the reasons above, realistic approach for the problem is to enhance product design which absorbs scatter in production process and boundary conditions. Conventional methods based on design space scan[4] only visualize non-linear transformation of input/output variables, which illustrate relationship of scatters, and physical mechanisms and how scatters propagate is a black box.

In this study, scatter propagation mechanism is visualized based on statistical calculation, and structural design is enhanced in order to reduce scatter using the front side structure of an automobile as an example. A process for analyzing scatter propagation mechanisms using statistical analysis software DIFFCRASH is proposed. The trigger of bifurcation is located, selection of deformation mode is made, mechanism of the bifurcation is studied, and design modification is made to stabilize the deformation mode.

Agile robustness analysis approach using DIFFCRASH

In recent years, robustness analysis becomes more and more important while development cycle has become shorter than ever. Conventional approaches of robustness analysis using response surface method have the following issues.

1. Hundreds of simulation results are required to build up a response surface in order to assure the accuracy of prediction. Conducting analysis without sufficient number of runs has high risk of approximation error so that engineers need to wait until enough runs are made.
2. Setting up output variables for evaluation requires good understanding of the problem. However it is difficult to know which part of the model is the key of the problem in advance of analysis. If key signals are not included in output variables, the response surface can mislead to wrong decisions.
3. Most of cases only initial conditions and final status of output values are discussed, and timing and spatial information, which is essential to understand phenomena, are neglected.
4. Validity of the response surface is not guaranteed once any change which is not in the scope of the analysis is made to the structure or boundary conditions, since products these days are

highly non-linear systems. For instance in car industry, when change in number and position of spot welds are made by another group after a response surface is made, another set of 100 runs may need to be made with the new design.

5. If there are bifurcations in the system, quality of the response surfaces cannot be assured in the vicinity of the boundary.

In order to tackle the issue, an agile robustness analysis approach using software DIFFCRASH is proposed. DIFFCRASH is a visualization tool for scatter in simulation which is developed by SIDACT GmbH. BASIC method of DIFFCRASH analyses scatter of nodal coordinate from multiple FE simulation runs and visualizes the results with contour plot in animation plot. Left side of Fig.1 shows an overlay of simulation results with scatter, and right side shows visualization by DIFFCRASH.

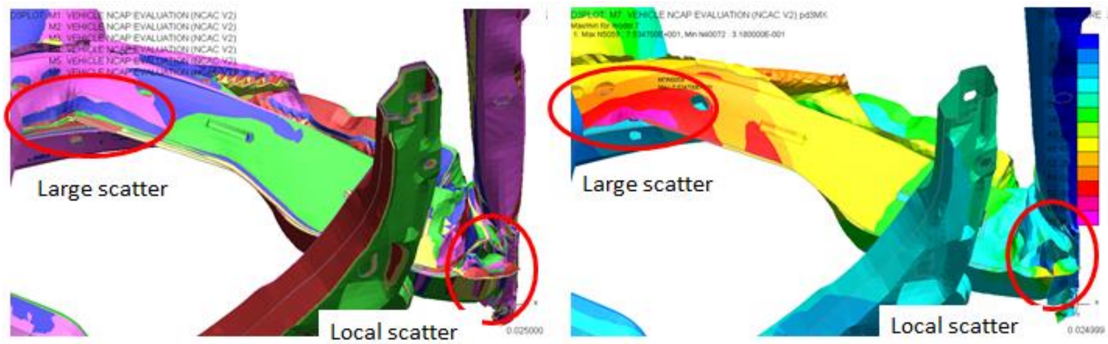

Fig.1: Example of scatter visualization result by DIFFCRASH BASIC method

DIFFCRASH has the following advantages for agile development process.

1. 20-30 simulation runs are enough for rough analysis, which is much less number compared with conventional response surface method. However, total amount of information is much more, since animation contains information on timing, location and propagation path of scatters.
2. Setting up output variables is not mandatory, since results are embedded to all nodes in animation file so that there is much less risk of overlooking sources of scatter.
3. PCA (Principle Component Analysis) method visualizes extreme results of the set of simulation runs which gives engineers idea on tendency of scatter.

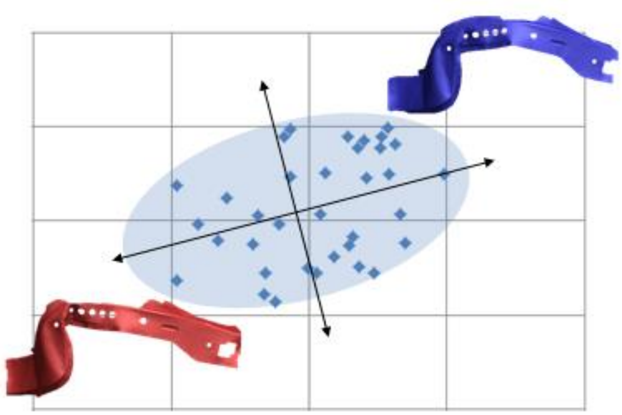

Fig.2: Schematics of the result of PCA method (red and blue are the extreme results)

Fig.3 shows an iterative DIFFCRASH analysis along with function development reduces risks of instability issues.

With analysis by DIFFCRASH, engineers can start analysis with small number of simulation results so that risks of being obsolete is relatively low, and as long as the validity of the FE model is assured, there is no risk of approximation error which can happen in response surface method.

Important questions on robustness issue, "where, when, and what" are visualized by DIFFCRASH so that engineers can concentrate only on "why and how". Animation with embedded scatter information helps engineers to understand the mechanism of robustness issues.

Once mechanism of scatter initiation and propagation is studied, countermeasures for more robust structure can be proposed to design team as feedbacks for next iteration of design change.

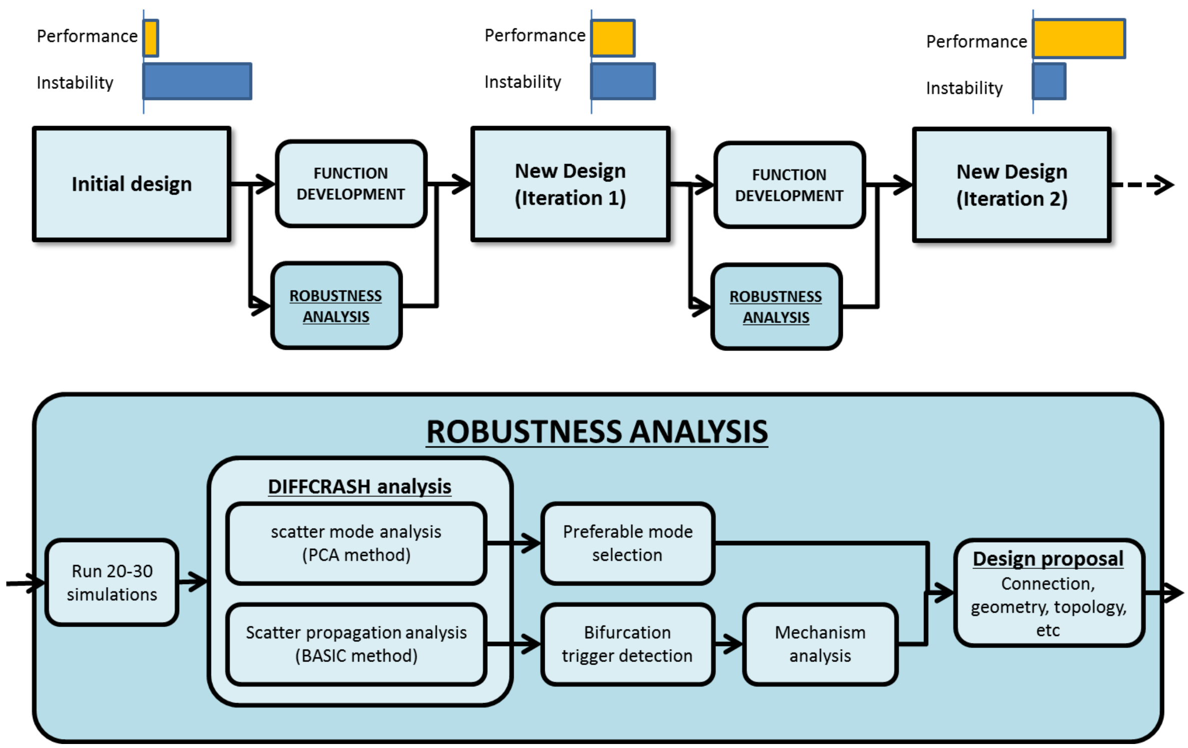

Fig.3: Proposed robustness analysis process

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